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Effects of growth retardants on Kentucky bluegrass growth and development.

Anna G. Symington
University of Massachusetts Amherst

EFFECTS OF GROWTH RETARDANTS ON KENTUCKY BLUEGRASS GROWTH AND DEVELOPMENT

A Thesis Presented

By

ANNA G. SYMINGTON

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Approved as to style and content by:

Lyle E. Craker, Chairman of Committee

Joseph Troll, Member

Stephen J. Herbert, Member

Allen V. Barker, Department Head
Plant and Soil Sciences

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CHAPTER I

INTRODUCTION

Maintenance of cool-season turfgrass along highway roadbanks, athletic fields, and numerous other non-agricultural areas requires frequent mowing throughout the growing season. These mowings, costing millions of dollars, are required to maintain turf at an attractive and functional height plus remove unsightly seedheads that grow above the turf canopy. A reduction in mowing frequency would reduce management costs.

In recent years, chemical retardants that reduce vegetative growth and suppress seedhead development have been tested (4, 6, 8-11, 16, 18, 22-26). However, their commercial use has been limited to "rough" turfgrass areas such as highway right-of-ways and cemetaries because of a leaf chlorosis developing on the grass plant 3 to 4 weeks following treatment with the chemicals (16). The chlorosis first appears on leaf tips, subsequently progressing down the leaf margins of mature, fully expanded leaves. The result is a yellow-colored turf unacceptable in intensively managed turfgrass areas such as parks and homelawns.

The degree of chlorosis following growth retardant treatment has previously been associated with midsummer environmental stress conditions (9, 16) raising the possibility that water and temperature stresses are contributing factors to leaf injury. Zukel (29) observed color losses when growth retardant applications were made to Kentucky bluegrass under serious moisture stress. Other researchers (20, 21) have demonstrated that bluegrass growth is seriously affected by temperature changes which are common within its growing area.

The objective of this research was to investigate the effects of chemical growth retardants on Kentucky bluegrass, studying the morphological changes and injury incurred with application of these chemicals, and the role of temperature and water stress in the development of injury.

CHAPTER II

LITERATURE REVIEW

Several chemical growth retardants have demonstrated the capacity to reduce vegetative growth and seedhead formation. Two growth retardants which are commercially available are maleic hydrazide (MH) and mefluidide (EMBARK). MH, formerly MH-30, was first tested in 1949 for grass growth suppression and found to be highly effective (22). Experiments have been done on 500 acres of Connecticut parkways since 1950 to develop the use of MH to reduce mowing costs (29). In 1960, approximately 2000 acres of highway were tested with MH in seven states countrywide (29). This program was extended to include more states in years to come. During the 1960's, researchers were working on the development of grass growth retardants that would be highly effective under a wide range of conditions and were testing improved forms of MH (5, 13). Experiments initiated by Zak and Bredakis (28) showed that treatment with MH-30 did not entirely eliminate mowing, but did reduce yields of dry matter substantially. This reduction in yields necessitates less subsequent mowing. Contrary to these findings, Chamberlin (2) reported erratic and inconclusive results with MH-30. Watschke (24) noted that the density of turf treated with MH was reduced 20% over untreated turf.

Mefluidide, formerly MBR-12325, is a foliarly absorbed growth retardant but the mechanism of action by which it suppresses turf growth is not fully understood. Growth of a grass blade takes place at its base through cell division and elongation, and it is in this area that mefluidide regulates growth (31). Mefluidide was shown in studies by Elkins, Vandeventer, and Briskovich (11) to reduce Kentucky bluegrass topgrowth. Research by other workers (4, 16, 18, 25) confirmed these findings and demonstrated that mefluidide is also an effective seedhead inhibitor.

EL-500, PP-333, and MBR-18337 are growth retardants that remain at the experimental level. Studies by Watschke (25) found that PP-333 and EL-500 were slower acting than mefluidide, but were ultimately more effective in reducing growth of 'Merion' Kentucky bluegrass. Results of Dernoeden's study (4) concurred that EL-500 at 2.24 and 3.36 kg/ha provided the best season-long growth retardation. Both MBR-18337 and mefluidide were significantly more effective in inhibiting seedheads than either PP-333 or EL-500, but the latter two reduced culm length (25). No reduction in turf density was reported for any of the treatments in these studies.

The adverse effects associated with these growth retardants (chlorosis of mature leaf tissue) appear to vary depending on the chemical itself or the rate at which it is applied. Dernoeden (4) observed that mefluidide and MBR-18337-treated plots did sustain loss of density. These turf plots also exhibited the highest percentage of leaves bearing *Helminthosporium vagans*-Drechsler (3) leaf spot lesions which could contribute to a lower quality in turf appearance. The appearance of turf treated with EL-500 was adversely affected by the presence of senescent, brown-colored foliage as a result of treatment. PP-333 - treated turf appeared darker green and denser than untreated turf (17). The attractiveness of the darker green, dense turf was soon followed by leaftip and marginal chlorosis of older leaf tissue. Combinations of PP-333 with mefluidide provided season-long grass and seedhead control but leaf injury was still prominent.

Jagschitz (18) obtained good growth suppression of Kentucky bluegrass with MBR-18337, EL-500, PP-333, and mefluidide, as well as combinations of mefluidide with EL-500 or PP-333, but found that all chemicals used had the potential of causing injurous effects, some of which were rather objectionable.

Hurto (16) observed in a 1980 study that injury from EL-500 was more pronounced than from mefluidide, and increased under midsummer stress. Turfgrass injury symptoms included a yellow cast to the turf with some tip die-back. Most injury was associated with older, elongated leaf tissue. Younger leaf tissue and basal tiller development had good color with no injury. However, since this leaf tissue is located in the lower regions of the plant canopy it did not contribute to quality ratings of turf appearance. Combination treatments of EL-500 and mefluidide increased the suppression of vegetative growth and seedhead formation as compared to the single application of the chemicals, but they also increased turfgrass injury.

Of primary importance among several environmental factors which may influence the production and maintenance of turf are seasonal variations in temperature, amount and intensity of sunlight, and cutting and fertilizer practices (14). Kentucky bluegrass grows best during cool seasons, but when cut short and heavily watered, especially during the hot summer months, the turf thins, the production of new leaves ceases, and large numbers of plants fail to recover during fall (14).

Information provided by the 3M Company (31) indicated that turf under drought conditions, or other stress, will not respond to mefluidide treatment because the chemical is not fully absorbed or translocated to the stem apex. Should a period of drought occur after mefluidide application, brown leaf discoloration becomes evident and does not disappear until the regulating effects of mefluidide diminishes.

All currently available growth retardants are not acceptable for use on fine quality turf. The growth retardants either do not control both growth and seedhead formation, or produce leaf injury.

CHAPTER III

MATERIALS & METHODS

Plant material. Kentucky bluegrass, *Poa pratensis* c.v. 'Merion', a perennial sodforming grass, was selected for use in these studies because of its wide use in the cool, humid regions of the northeastern and midwestern United States (9, 21). Plant material used in these studies was located at or selected from the University of Massachusetts Experimental Turf Plots in South Deerfield, Massachusetts. The grass in the plots was maintained at a cutting height of 5 cm and fertilized in April and mid-June with a 20-18-12 fertilizer at a rate of 0.45 and 0.23 kg N per 92.9 m^2, respectively. The basic field soil type was a Hadley Silt Loam (Mesic Typic Udifluvents).

For field studies, individual experimental plots, 0.9 m x 2.1 m, were established during the spring of 1981. All the plots including controls were mowed at a cutting height of 5 cm (with grass clippings collected) 2 days prior to growth retardant application and again 10 days following chemical application to remove flowering culms. Control plots were mowed weekly at a cutting height of 5 cm (with grass clippings collected) while unmowed plots were not mowed throughout the duration of the study.

For greenhouse and stress studies, individual, uniformly sized tillers selected from 10-cm grass core samples (obtained from an untreated field plot) were potted in 473 cc (16 oz) styrofoam cups, 3 (greenhouse study) or 5 (stress study) plants per cup. Each styrofoam cup was filled to within 1.27 cm of the cup rim with a potting mixture of sand:peat (5:3 v/v), selected to provide easy handling, good water drainage, rapid root penetration and minimal compaction. All plants were acclimated to greenhouse conditions (minimum temperature of 21^{o}C) and to environmental growth chambers (temperature of 21^{o}C) for 6 weeks before chemical application. All plants were maintained at a height of 4 cm up to time of chemical treatment and fertilized weekly with a half-strength Hoagland's solution (15). Cups containing plants were randomly repositioned once a week.

Chemical applications. Mefluidide, a commercially available growth retardant, and EL-500, PP-333, and MBR-18337, 3 experimental growth retardants, were studied (Table 1). Application of growth retardants in all studies (Tables 2 and 3) was made with a CO_2-powered backpack sprayer at 3.44 x 10^5 Pa (50 psi). Growth retardants were applied to grass plants in the field study on May 8, 1981. Chemical treatment to greenhouse and stress studies were initiated after the 6-week acclimation period. Plants treated with the root absorbed chemicals, EL-500 and PP-333, were watered within an hour after treatment in order to wash the chemical from the foliage and insure penetration of the chemical into the soil.

Environmental stress conditions. Environmentally controlled growth

TABLE 1

GROWTH RETARDANTS USED IN FIELD, GREENHOUSE, AND ENVIRONMENTAL STRESS STUDIES.

Growth Retardant	Chemical Formula
Mefluidide (2S)	N-(2,4-dimethyl-5-(((trifluoromethyl)-sulfonyl)amino)phenyl)acetamide
EL-500 (50W)	(1-methyl ethyl)-(4-(trifluoromethoxy) phenyl)-5 pyrimidinemethanol
PP-333 (50W)	(2R,3R - 2S,3s)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)pentan-3-ol
MBR-18337 (2E)	Undisclosed

TABLE 2

APPLICATION RATES OF GROWTH RETARDANTS

	Mefluidide	EL-500			PP-333			MBR-18337		
	Rates of Application (kg/ha)									
		Low	Med	High	Low	Med	High	Low	Med	High
Study	0.42	0.84	1.12	1.68	2.24	3.36	4.48	0.13	0.28	0.56
Field	X	X	X	X	X	X	X	X	X	X
Greenhouse	X	X		X	X		X	X	X	
Environmental Stress	X	X			X					

X, This rate of growth retardant used.

TABLE 3

APPLICATION RATES OF GROWTH RETARDANT COMBINATIONS.

Compound combinations (kg/ha)			Study: Field	Study: Greenhouse
EL-500	+	Mefluidide		
0.84		0.06	X	X
0.84		0.12	X	
1.12		0.06	X	
1.12		0.12	X	
PP-333	+	Mefluidide		
0.28		0.06	X	X
0.28		0.12	X	
0.56		0.06	X	
0.56		0.12	X	

X, This rate of growth retardant used.

chambers were used for induction of a five week temperature and/or water stress period to grass plants one week after growth retardant treatment. A uniform group of potted plants was evenly divided into 2 groups, each group then placed into growth chambers which were maintaining different temperature regimes.

The induced temperature stress was 31°C with a 21°C temperature serving as a controlled, non-stressed condition. The induced water stress was imposed on one-half the plants under each temperature regime by watering with half-strength Hoagland's solution only when plants showed signs of wilt. Control, non-water stressed plants received water 3 times a week (twice with distilled water, once with half-strength Hoagland's solution). Cups containing plants were always watered to field capacity, as indicated by drainage from holes in the bottom of the cup.

Observations.

Growth. The movable disc method (24) was used to measure turf height at selected dates beginning 2 weeks after chemical treatment with each measurement representing an average of 3 random height measurements within each plot. For greenhouse and stress studies, height was measured using a meter ruler with recorded height representing the measurement from the soil surface to the observed turf top.

Shoot development. Plant development was determined through tiller and seedhead counts, and by the total dry matter yield of all vegetative plant material.

Tiller numbers were counted at the termination of greenhouse and stress studies. Seedhead inhibition was determined in the field at selected dates by tossing a metal ring with an area of 314 cm^2 once randomly into each plot and counting the seedheads within the ring.

Dry matter yield was determined at termination of field studies by collecting plant material from a centrally located 0.3 m x 1.5 m section of each plot above a cutting height of 5 cm with a rotary mower and attached collection bag. At termination of greenhouse and stress studies, grass plants were clipped at the soil surface and the clippings collected in paper bags. Dry matter yield was determined after drying all the plant material to a constant weight at 65°C.

Quality. Turf quality was estimated on selected dates beginning 2 weeks after growth retardant treatment by visual observations of plant material. A quality rating system of 1 through 9, based on turf color, density, uniformity, and injury was used to score all plants. A score of 9 represented a perfect turf (green, lush growth, uniform in height); a score of 7 to 9 was considered good quality turf; a score of 4 to 7 was considered fair quality turf; and a score of 1 to 4 was considered poor quality turf. A quality rating below 6 indicated unacceptable turf quality. A rating of 5 or below indicated turf thinning, leaf chlorosis, lack of height uniformity, or a combination of these variables. A rating of 1 represented a dead or patchy turf.

Experimental design and data analysis. Field studies were arranged in a completely randomized block design and greenhouse studies were arranged in a completely randomized design with 3 and 10 replications, respectively. Due to the large number of different application rates in the field, standard errors were developed by analyzing the field study as a completely randomized design.

Environmental stress studies were arranged as a 4 x 4 x 5 factorial design. Data were tested for significance using analysis of variance.

CHAPTER IV

RESULTS

Morphological effects.

Growth. Shoot height measurements of turf in the field confirmed mefluidide's ability to retard growth in comparison with unmowed controls (Table 4). Mefluidide-treated plants were reduced in height 20% as compared with unmowed controls by two weeks after application. MBR-18337-treated plants showed a 20% reduction in shoot height, responding similarly to plants treated with mefluidide. The growth retardation of plants treated with EL-500 or PP-333 became evident 3 to 4 weeks after chemical treatment. EL-500 and PP-333 were still maintaining shoot reduction at termination of the field study having a 46% and 56% height reduction, respectively, compared with unmowed controls. The retarding abilities of mefluidide and MBR-18337 had already begun to diminish by termination of the field study.

Combination treatments of EL-500 or PP-333 with mefluidide proved to be good growth retardant combinations. Upon termination of the field study, mefluidide combinations with the high rates of EL-500 and PP-333 were maintaining a 40% and 54% height reduction, respectively.

Height measurements of chemically treated plants growing in the greenhouse concurred with field observations (Table 5) indicating

TABLE 4

GROWTH OF TURFGRASS TREATED WITH CHEMICAL RETARDANTS IN THE FIELD.

Treatment	Rate (kg/ha)	Weeks After Application: 2 wks	5 wks	8 wks
		cm		
Unmowed control	---	5.66 ±0.16[1]	10.16 ±0.16	15.66 ±0.33
Mefluidide	0.42	4.50 ±0.28	6.16 ±0.16	11.50 ±0.50
EL-500	0.84	6.00 ±0.28	8.16 ±0.44	11.66 ±0.82
EL-500	1.12	5.56 ±0.23	9.00 ±1.32	11.66 ±2.42
EL-500	1.68	6.00 ±0.28	7.50 ±0.50	8.33 ±0.33
PP-333	2.24	5.33 ±0.16	7.16 ±0.33	7.16 ±0.60
PP-333	3.36	5.00 ±0.28	7.00 ±0.28	7.00 ±0.50
PP-333	4.48	5.16 ±0.16	6.66 ±0.44	7.00 ±0.28
MBR-18337	0.13	4.66 ±0.33	6.66 ±0.16	13.50 ±0.50
MBR-18337	0.28	4.66 ±0.16	7.16 ±0.16	12.00 ±1.00
MBR-18337	0.56	4.33 ±0.16	5.50 ±0.28	12.50 ±1.15

TABLE 4 CONTINUED

Treatment	Rate (kg/ha)	2 wks	5 wks	8 wks
			cm	
EL-500 + Mefluidide	0.84 +0.06	5.16 ±0.44	5.83 ±0.16	10.00 ±0.50
EL-500 + Mefluidide	0.84 +0.12	5.00 ±0.28	6.00 ±0.00	11.16 ±0.60
EL-500 + Mefluidide	1.12 +0.06	4.83 ±0.16	5.66 ±0.33	9.33 ±0.33
EL-500 + Mefluidide	1.12 +0.12	5.00 ±0.28	5.50 ±0.28	10.00 ±1.00
PP-333 + Mefluidide	0.28 +0.06	4.83 ±0.33	6.00 ±0.57	10.33 ±0.88
PP-333 + Mefluidide	0.28 +0.12	4.66 ±0.16	5.66 ±0.44	10.33 ±0.72
PP-333 + Mefluidide	0.56 +0.06	4.66 ±0.16	5.33 ±0.33	7.16 ±0.44
PP-333 + Mefluidide	0.56 +0.12	4.83 ±0.16	5.50 ±0.28	7.16 ±0.60

[1]Means ± s.e.

TABLE 5

GROWTH OF TURFGRASS TREATED WITH CHEMICAL RETARDANTS IN THE GREENHOUSE.

Treatment	Rate (kg/ha)	Weeks After Treatment 2 wks	5 wks	8 wks
		cm		
Control	---	5.27 ±0.26[1]	5.34 ±0.19	4.57 ±0.16
Mefluidide	0.42	5.08 ±0.21	3.56 ±0.28	5.39 ±0.17
EL-500	0.84	4.89 ±0.28	3.05 ±0.21	1.90 ±0.13
EL-500	1.68	4.89 ±0.21	2.34 ±0.23	1.46 ±0.09
PP-333	2.24	4.95 ±0.16	3.30 ±0.22	1.65 ±0.16
PP-333	4.48	5.21 ±0.16	3.36 ±0.19	1.90 ±0.21
MBR-18337	0.13	4.82 ±0.19	3.43 ±0.16	3.87 ±0.20
MBR-18337	0.28	4.64 ±0.16	3.30 ±0.21	3.04 ±0.21
EL-500 + Mefluidide	0.84 +0.06	5.02 ±0.14	2.16 ±0.33	2.35 ±0.16
PP-333 + Mefluidide	0.28 +0.06	5.46 ±0.16	1.91 ±0.31	1.14 ±0.08

[1]Means ± s.e.

the significant growth retarding abilities of these chemicals. Under greenhouse conditions, EL-500 and PP-333 proved to be superior in growth reduction and persistence as compared with mefluidide and MBR-18337. EL-500 and PP-333 also caused greater leaf injury to treated plants as compared with mefluidide and MBR-18337.

Shoot development. In field and greenhouse studies, there was a significant reduction in shoot dry weights of plants treated with growth retardants in comparison with untreated, uncut controls (Tables 6, 7, 8). EL-500 and mefluidide-treated plants had no significant reductions in shoot dry weights under greenhouse conditions (Table 8).

Tiller counts obtained on plants treated in the greenhouse indicated that growth retardants could increase tiller production (Table 8). EL-500-treated plants had a significant increase in tiller formation as compared with untreated controls. The combination of PP-333 and mefluidide decreased tiller formation. There appeared to be no effects on tiller production from treatment with the other growth retardants.

Comparison of mowed and unmowed field plots indicated that weekly mowing prevented objectionable seedhead appearance whereas seedheads were profuse in unmowed field plots (Table 9). Mefluidide and MBR-18337 suppressed seedhead formation and were comparable to mowed field plots. EL-500 and PP-333 did not suppress seedheads, comparable to unmowed controls. EL-500 and PP-333 in combination with mefluidide suppressed seedhead production.

TABLE 6

DRY MATTER PRODUCTION OF GRASS TREATED WITH GROWTH RETARDANTS IN THE FIELD.

Treatment	Application Rate: Low	Medium	High
	---------(g dry wt/m^2)---------		
Mefluidide	141.0 ± 27.16[1,2]		
EL-500	217.0 ± 44.50	184.0 ± 52.24	90.0 ± 19.00
PP-333	32.0 ± 0.46	38.0 ± 3.24	40.0 ± 1.51
MBR-18337	190.0 ± 34.84	180.0 ± 20.53	150.0 ± 44.16
Unmowed control	314.0 ± 33.91[2]		
Mowed control	19.0 ± 2.80[2]		

[1]Mean ± s.e.
[2]Application at only one rate, or no chemical application.

TABLE 7

DRY MATTER PRODUCTION OF GRASS TREATED WITH GROWTH RETARDANT COMBINATIONS IN THE FIELD.

Rate (kg/ha)	Mefluidide Rate: 0.06 kg/ha	0.12 kg/ha
	(g dry wt/m^2)	
EL-500		
0.84	119.26 ± 27.22[1]	119.38 ± 25.58
1.12	97.78 ± 20.40	89.31 ± 32.78
PP-333		
0.28	117.16 ± 20.31	140.64 ± 30.58
0.56	59.76 ± 13.24	58.13 ± 15.96

[1]Means ± s.e.

TABLE 8

SHOOT DEVELOPMENT IN GROWTH RETARDANT TREATED PLANTS IN THE GREENHOUSE.

		Shoot Development[1]	
Treatment	Rate (kg/ha)	(g dry wt)	(no. tillers)
Control	---	0.45 ± 0.05	27.83 ± 2.24
Mefluidide	0.42	0.43 ± 0.14	30.00 ± 2.98
EL-500	0.84	0.40 ± 0.12	33.80 ± 2.69
EL-500	1.68	0.40 ± 0.12	39.10 ± 2.21
PP-333	2.24	0.28 ± 0.08	29.11 ± 3.50
PP-333	4.48	0.32 ± 0.02	29.20 ± 1.87
MBR-18337	0.13	0.23 ± 0.02	35.44 ± 3.52
MBR-18337	0.28	0.14 ± 0.04	27.60 ± 2.82
EL-500 + Mefluidide	0.84 + 0.06	0.34 ± 0.11	33.30 ± 3.79
PP-333 + Mefluidide	0.28 + 0.06	0.25 ± 0.08	19.70 ± 1.68

[1]Mean ± s.e.

TABLE 9

SEEDHEAD DEVELOPMENT OF GRASS TREATED WITH GROWTH RETARDANTS IN THE FIELD.

Treatment	Low	Application Rate (seedheads/m^2)	Medium	High
Unmowed control		337 ± 43.95[1,2]		
Mowed control		- 0 -		
EL-500	312 ± 45.22		535 ± 124.20	376 ± 57.32
PP-333	515 ± 54.14		299 ± 12.74	204 ± 35.35
MBR-18337	- 0 -		- 0 -	- 0 -
Mefluidide		- 0 -		
EL-500 + Mefluidide		- 0 -[3]		
PP-333 + Mefluidide		- 0 -[3]		

[1]Means ± s.e.
[2]No chemical treatment to controls.
[3]Figures representative of all combination rates.

Turfgrass quality. Comparison of chemically treated plants to untreated controls in the field and greenhouse indicated a noticeable decrease in turf quality of the chemically treated plants by the third week after treatment (Figures 1-5).

Under field conditions, the mowed and unmowed controls maintained a quality rating of 7 or above throughout the study with no signs of leaf injury, a major contributing factor to the low quality ratings of turf treated with growth retardants (Figures 4, 5). Plants treated with mefluidide and MBR-18337 showed signs of

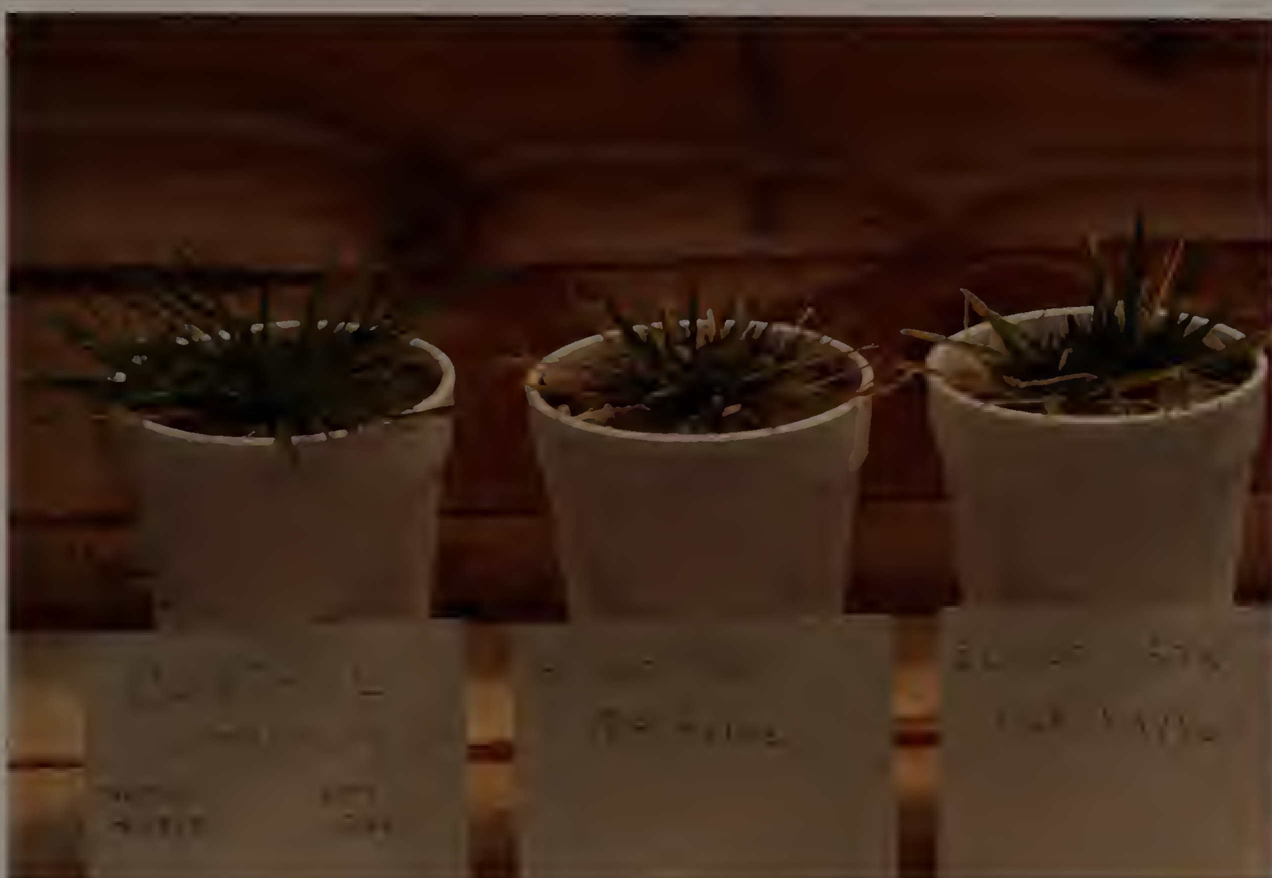

Fig. 1. Development of leaf injury of grass treated with growth retardants in the greenhouse. Photograph was taken 6 weeks after chemical application.

Fig. 2. Development of leaf injury of grass treated with growth retardants in the field. Photographs were taken 8 weeks after chemical application.

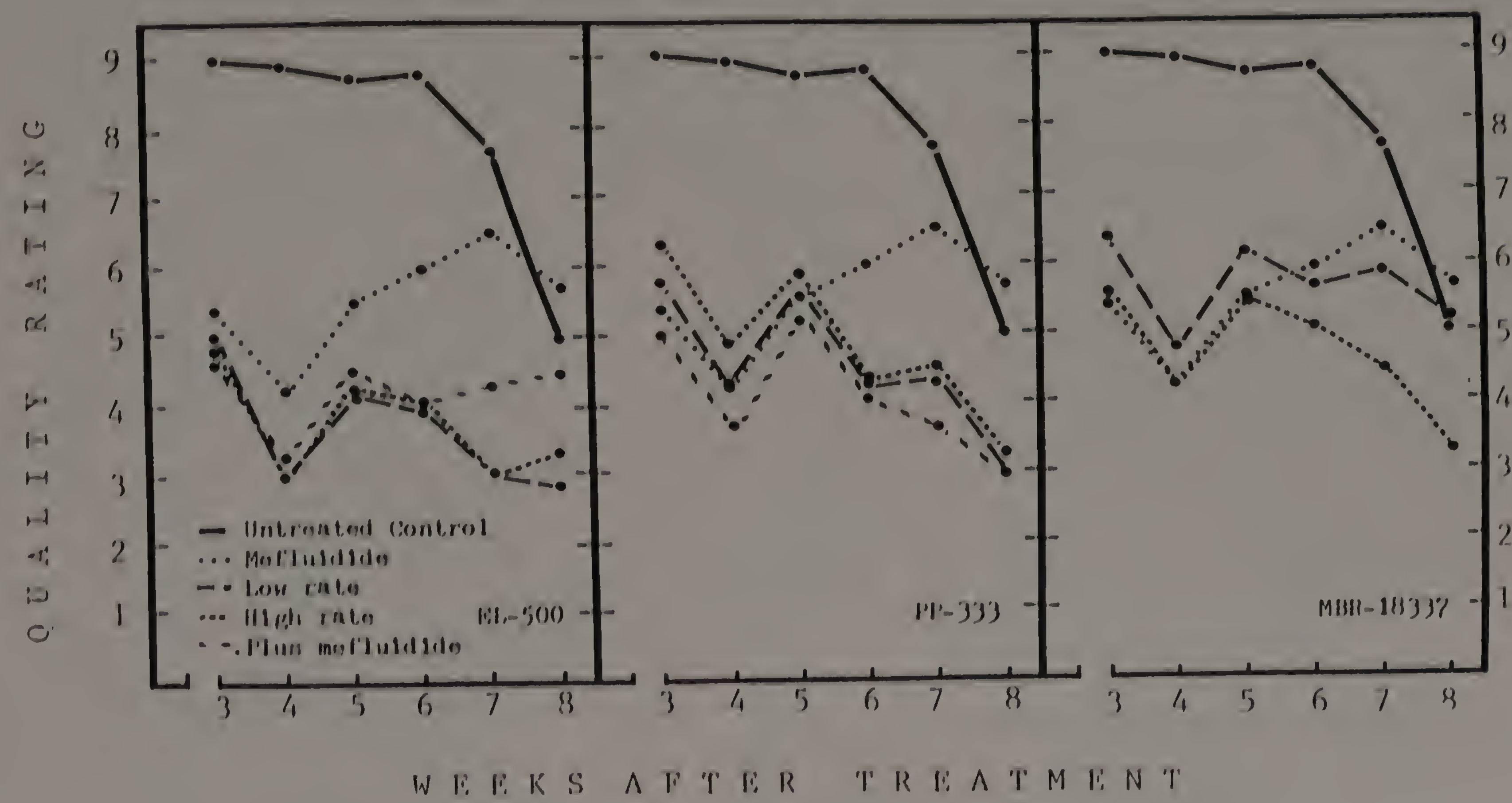

Fig. 3. Quality of turfgrass treated with growth retardants in the greenhouse. At time of treatment, all samples had a quality rating of 9.

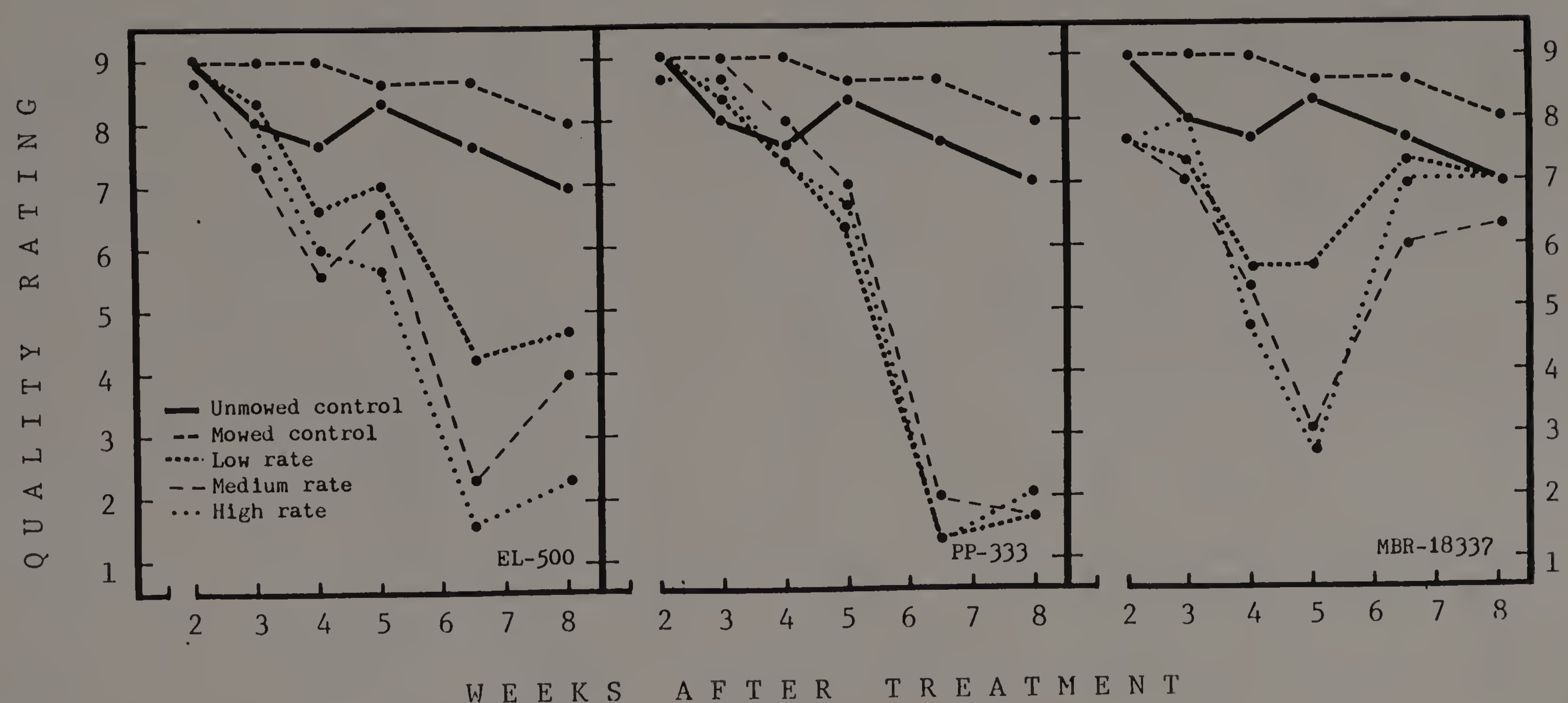

Fig. 4. Quality of turfgrass treated with growth retardants in the field. At time of treatment, all samples had a quality rating of 9.

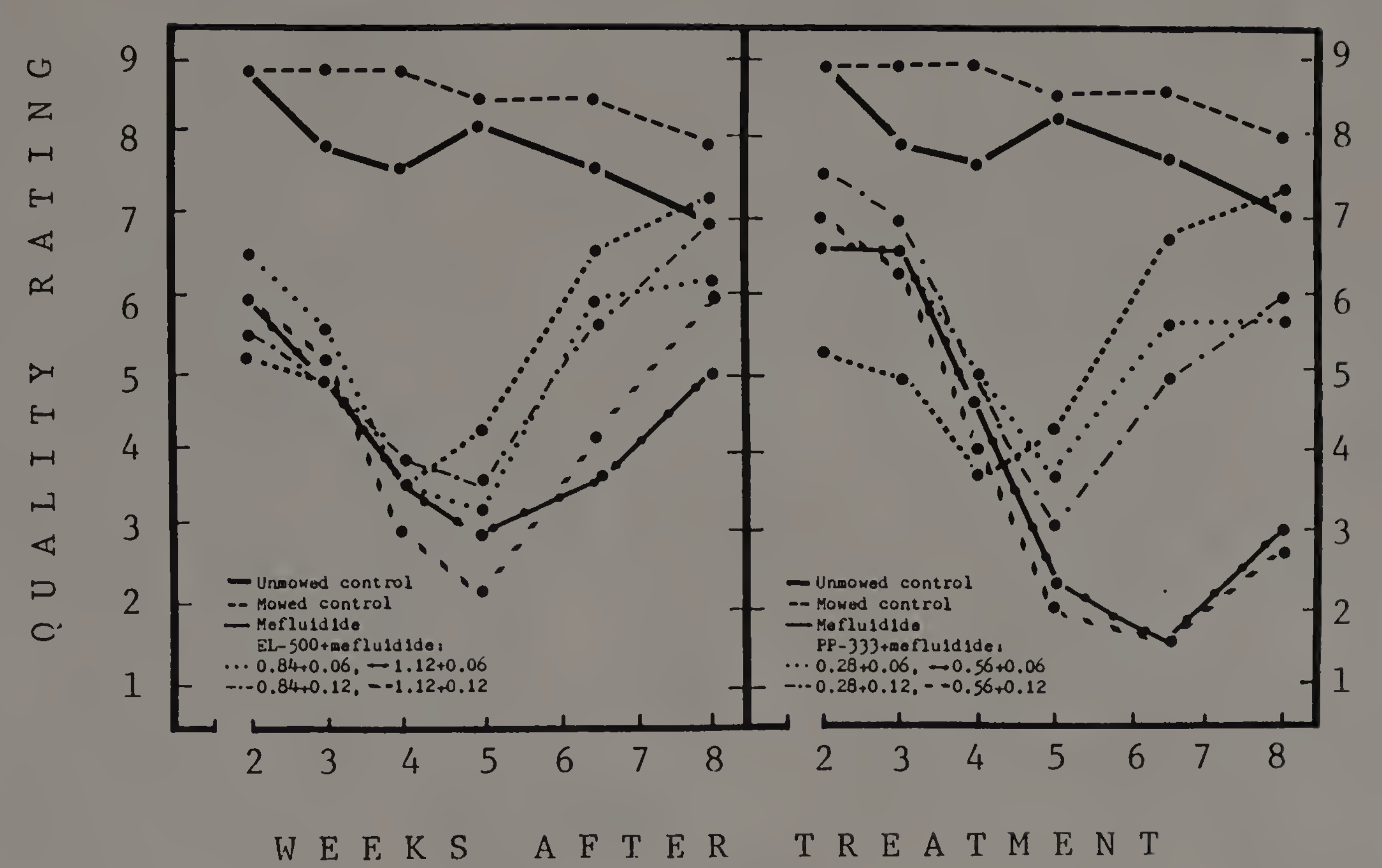

Fig. 5. Quality of turfgrass treated with growth retardant combinations in the field. At time of treatment, all samples had a quality rating of 9.

leaf injury and had quality ratings below 6 by four weeks after chemical treatment. Field plants treated with mefluidide also lacked uniformity, resulting in a low quality rating.

The injurous effects of mefluidide and MBR-18337 to plants in the field had diminished by the sixth week after treatment having quality ratings of 6 or higher; EL-500 and PP-333-treated plants continued to show severe signs of leaf injury having quality ratings below 5 (Figure 2). At the termination of the studies, plants treated with EL-500 were showing signs of recovery from injury, whereas PP-333-treated plants did not show any signs of recovery from injury (Figure 4).

Under field conditions, the combination of EL-500 and mefluidide produced quality ratings similar to the single application of mefluidide (Figure 5). The combination appeared to enhance the recovery rate of turf quality in both the field and greenhouse studies.

The combination of PP-333 and mefluidide caused a significant decrease in turf quality approximately 2 weeks earlier than the single application of PP-333 under field conditions. Turfgrass treated with the low rate of PP-333 in combination with mefluidide showed definite signs of recovery from injury at termination of the field study. Under greenhouse conditions, the PP-333-mefluidide combination enhanced leaf injury compared with single applications of PP-333 (Figure 3).

Environmental stress.

Growth. Growth retardants under environmentally controlled conditions supported field and greenhouse study findings. Under all tested environmental conditions, the application of growth retardants significantly reduced plant height in comparison with untreated control plants (Table 10). Untreated control plants were not reduced in height as a result of imposed temperature or water stress. The stress conditions did not influence the retarding abilities of growth retardants.

TABLE 10

GROWTH OF TURFGRASS TREATED WITH CHEMICAL RETARDANTS UNDER ENVIRONMENTAL STRESS.

	Stress Conditions			
Treatment	Control	Water	Temp	Water/Temp
	(cm)			
Untreated Control	22.9 ± 0.80[1]	22.1 ± 0.62	22.9 ± 1.26	21.9 ± 0.67
EL-500	4.7 ± 0.26	4.1 ± 0.29	4.3 ± 0.41	4.2 ± 0.37
PP-333	2.9 ± 0.29	3.2 ± 0.12	3.9 ± 0.10	4.0 ± 0.27
Mefluidide	2.9 ± 0.18	3.1 ± 0.10	2.9 ± 0.18	3.4 ± 0.10

[1]Means ± s.e. at 6 weeks after retardant treatment.

Shoot development. Tiller formation was influenced by treatment with growth retardants under non-stress conditions (Table 11). EL-500 significantly increased tiller formation in comparison with untreated control plants under non-stress conditions, similar to observations under greenhouse conditions. Both mefluidide and PP-333

TABLE 11

TILLER DEVELOPMENT OF TURFGRASS TREATED WITH CHEMICAL RETARDANTS UNDER ENVIRONMENTAL STRESS.

	Stress Conditions			
	Control	Water	Temp	Water/Temp
	(no. tillers per cup)			
Treatment				
Untreated Control	29.8 ± 4.91[1]	32.0 ± 4.32	19.2 ± 2.03	13.2 ± 2.13
EL-500	43.8 ± 4.56	36.8 ± 4.86	14.0 ± 1.76	19.2 ± 3.81
PP-333	25.4 ± 6.25	36.2 ± 3.61	15.8 ± 3.14	17.4 ± 1.63
Mefluidide	9.4 ± 2.54	6.6 ± 0.81	5.8 ± 1.82	6.4 ± 0.92

[1]Means ± s.e. at 6 weeks after retardant treatment.

reduced tiller formation under non-stressed conditions.

Water stress did not influence tiller production of untreated or treated plants, nor interfere with the ability of EL-500 to increase tiller formation.

Temperature stress decreased tiller production of untreated control plants nearly 40%. Temperature stress also reduced tiller formation of plants treated with EL-500 or PP-333 in comparison with plants treated with the same chemicals under non-stress conditions. The effects of mefluidide on tillering remained unchanged from non-stressed conditions.

The combination of temperature and water stresses caused a decrease of 56% in tiller formation of untreated control plants as compared with non-stress conditions. Temperature/water stress did not further increase nor decrease tiller formation of plants treated with growth retardants as compared with treated plants under temperature stress conditions.

Shoot dry weights of chemically treated plants under non-stress conditions were significantly reduced in comparison with untreated control plants in non-stress conditions (Table 12). Water stress did not influence dry matter yields.

TABLE 12

DRY MATTER PRODUCTION OF TURFGRASS TREATED WITH CHEMICAL RETARDANTS UNDER ENVIRONMENTAL STRESS.

	Stress Conditions			
	Control	Water	Temp	Water/Temp
	(g dry wt)			
Treatment				
Untreated Control	0.856 ± 0.06[1]	0.986 ± 0.03	0.506 ± 0.05	0.356 ± 0.02
EL-500	0.334 ± 0.04	0.306 ± 0.04	0.166 ± 0.02	0.168 ± 0.01
PP-333	0.168 ± 0.04	0.266 ± 0.03	0.142 ± 0.01	0.118 ± 0.03
Mefluidide	0.090 ± 0.01	0.076 ± 0.01	0.076 ± 0.01	0.066 ± 0.01

[1]Means ± s.e.

Temperature stress caused a 41% reduction in shoot dry weight of the untreated control plants as compared with non-stress conditions. Temperature stress also reduced dry matter yield of plants treated with EL-500 20% more than those plants treated with EL-500 under non-stress conditions. The reductions in shoot dry weight from treatment with PP-333 or mefluidide under non-stress conditions were not affected by temperature stress.

Temperature/water stress reduced shoot dry weight of untreated control plants 17% more than did temperature stress alone. Temperature/water stress did not further increase or decrease shoot dry weights of plants treated with growth retardants in comparison to treated plants under temperature stress.

Turfgrass quality. At the termination of the stress study, quality ratings of plants under non-stress conditions were comparable to field quality ratings at week 5 after treatment, with the untreated controls and EL-500-treated plants showing good quality ratings of 9.0 and 7.8 respectively. PP-333-treated plants showed marginal quality with a rating of 6.4 and mefluidide treated plants had a poor quality rating of 2.8 (Table 13).

Quality ratings of plants observed under non-stressed conditions were not changed as a result of imposed water stress, with the exception of EL-500-treated plants which decreased in quality by one point, to 6.8.

Temperature stress caused a decrease in quality of untreated control plants, from a quality rating of 9.0 (under non-stress conditions) to 8.4 (under stress conditions). The quality of plants treated with growth retardants was significantly decreased to ratings of 5.0 or below under temperature stress conditions.

The temperature/water stress combination did not cause any further decrease in quality than was observed under the temperature stress condition.

TABLE 13

QUALITY OF TURFGRASS TREATED WITH CHEMICAL RETARDANTS UNDER ENVIRONMENTAL STRESS.

	Stress Conditions			
Treatment	Control	Water	Temp	Water/Temp
Untreated Control	9.0 ± 0.0[1]	9.0 ± 0.0	8.4 ± 0.2	8.0 ± 0.0
EL-500	7.8 ± 0.2	6.8 ± 0.4	5.0 ± 0.7	5.8 ± 0.7
PP-333	6.4 ± 0.6	6.8 ± 0.2	4.8 ± 0.9	4.4 ± 0.8
Mefluidide	2.8 ± 0.6	2.6 ± 0.5	1.4 ± 0.2	1.6 ± 0.2

[1]Means ± s.e. at 6 weeks after retardant treatment. At time of treatment, all samples had a quality rating of 9.

CHAPTER V

DISCUSSION AND CONCLUSION

It is evident that the growth retardants used in this and other studies (4, 6, 8-11, 16, 18, 23-25) have the ability to retard turf growth. Treatment of plants with growth retardants produced significant reductions in turf height under field and greenhouse studies illustrating the potential of these chemicals to reduce mowings and costs associated with mowing. Unfortunately, leaf injury associated with application of growth retardants to grass produces an unacceptable quality for fine turf.

There were significant differences among the tested growth retardants as to the time plants responded to chemical treatment. Mefluidide and MBR-18337 produced retardation effects earlier than EL-500 and PP-333, possibly due to the former chemicals being foliarly absorbed. EL-500 and PP-333 were superior to the foliarly absorbed chemicals in height suppression, both in the percent reduction and persistence. PP-333 provided season-long height reduction under field conditions and there were carry-over retardation effects observed in the following year, similar to that noticed by other researchers (23). The activity of mefluidide appeared to be short-lived as compared with the other growth retardants studied. Upon termination of the study, those plants treated with mefluidide were no longer retarding shoot growth while EL-500 and PP-333-

treated plants were still showing signs of reduction.

Measurements of shoot dry weights indicated that dry matter yield was significantly reduced by chemical treatments and corresponded closely with the height measurements. Shoot dry weights appeared to be a reliable indication of growth retardation effectiveness. Even though growth was reduced under greenhouse conditions, EL-500-treated plants did not show a decrease in dry weight because of the increase in tiller and leaf formation.

Seedhead suppression is an important factor when considering a growth retardant. MBR-18337 proved to be as effective as the commercially available mefluidide in suppressing seedheads. Although seedhead control was ineffective with EL-500 or PP-333, culm length was reduced so that the seedheads remained within the turf canopy, creating an undesirable turf appearance as they matured and senesced. EL-500 and PP-333 were only effective in suppressing seedheads when in combination with mefluidide and this is apparently due to the mefluidide component. EL-500 and PP-333 show best potential as growth retardants when in combination at low rates with mefluidide.

The leaf injury caused by growth retardant applications is a major problem preventing wide use on a commercial basis. Despite the retardation abilities of a chemical, it is unusable on fine turf areas if it destroys the aesthetic appearance of a fine turf.

Although mefluidide is a commercially available product and caused leaf injury, the injurous effect was short-lived (approximately 4 weeks). MBR-18337 appears to have the same characteristics as mefluidide and shows the best results (good growth reduction and low leaf injury) at the low application rate. Although leaf injury was a major factor contributing to low quality ratings of mefluidide and MBR-18337-treated turf, quality was also affected by an apparent loss of density following the growth retardant application; this observation acknowledged by other researchers (4, 26). The loss of density was more pronounced from treatment with mefluidide than with MBR-18337.

Leaf injury from growth retardant application resembled senescing tissue. The older leaves became chlorotic at the tips with tissue injury progressing down the leaf margins, followed by eventual death of the leaf. Uncut leaves are organs of limited growth and once they attain their final size, remain on the plant for a limited time period before dying (19). As senescence progresses, cell constituents are mobilized and redistributed, so the leaf actually loses weight. Leaf vigor declines and photosynthetic activity falls after a leaf is fully expanded. The data are consistent with the hypothesis that growth retardants are hastening this aging process with longevity of the leaf actually shortened because the leaves reach their maximum size at an earlier or faster rate than those leaves on an untreated control plant. As new leaves and tillers emerge they accumulate assimilates from older leaf tissue (19). This process could explain the extended injury from application of EL-500 or PP-333 as those plants treated with these chemicals appear to be producing many leaves in a shorter period of time than the untreated control plants.

The possibility of temperature or water stress enhancing this injury was investigated under environmentally controlled conditions. Many turfgrasses undergo growth retardation during the summer when under drought (21) and/or temperature stress (20,21). Our results indicated that a high temperature regime (30^{o}C) enhanced the leaf injury observed from growth retardant treatment. Studies by McKell (20) suggested that accumulation of carbohydrates may be an important factor in the ability of Kentucky bluegrass to withstand environments where less than favorable temperatures exist. At a temperature of 30^{o}C, a large portion of carbohydrate reserves was depleted suggesting that most of the available photosynthate was used in respiration rather than in the production of new growth (20). Temperature stress appears to amplify the injurous effects of growth retardant application on turf. This could explain the observed low quality of turf in the field following a warm period (30^{o}C or above) the third week after chemical application as the quality of the chemically treated turf was significantly reduced.

Water stress did not enhance injury or cause any significant differences among chemically treated plants. Research by Watschke (25) suggests that growth retardant-treated turf is more resistant to wilt than non-treated turf as soil moisture measurements taken under a Merion sod treated with EL-500 or PP-333 showed a better moisture status than soil under untreated Merion sod. This would explain why chemically treated plants in our water stress study required water approximately every 7 to 10 days as compared with untreated control plants which required watering more frequently. Possibly the reduced foliar growth created a lower transpirational demand and water was conserved.

These studies have indicated that treatment of Kentucky bluegrass with selected commercial and experimental growth retardants results in effective height control and seedhead suppression, both desirable characteristics for maintenance of fine turf. Despite the good retardation abilities of these chemicals, their application to turf resulted in unacceptable leaf injury, lowering turf quality. The leaf injury increases under midsummer stress with temperature stress appearing to be the responsible factor.

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